Factors influencing occupancy of modified artificial refuges for monitoring the range-restricted Banks Peninsula tree weta *Hemideina ricta* (Anostostomatidae)

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Abstract: The use of non-destructive and non-invasive monitoring methods is often necessary for species of high conservation status. Developing monitoring methods to maximise numbers of individuals found is important, given that rare species can be difficult to locate. Artificial refuges called 'weta motels' have been used for monitoring tree weta (Orthoptera: Anostostomatidae) since 1992, but poor occupancy for *Hemideina ricta* and *H. femorata* necessitated an improved design and assessment of placement to encourage tree weta use. Modification to a basic design of weta motel was tested on New Zealand's rarest tree weta, *H. ricta*, on Banks Peninsula, Canterbury, New Zealand. Possible lures such as peanut butter or frass from male and female *H. ricta* were placed in motels in an attempt to improve occupancy. We recorded high occupancy rates with an improved weta motel design and found that motels containing female frass had significantly higher levels of occupancy than controls, with the former reaching 80% occupation after 6 months. Weta motels were more likely to be used by tree weta in areas with low subcanopy density and patchy or little canopy cover, with *H. ricta* found to prefer higher altitude sites. Occupation of weta motels was compared with results from a previous hand search survey, finding very similar distributions of tree weta species with the two survey methods. We conclude that this modified refuge is effective for monitoring tree weta, including the range-restricted Banks Peninsula tree weta *H. ricta*.

Keywords: conservation; distribution; *Hemideina femorata*; restoration; weta motels

Introduction

Monitoring rare or threatened species non-destructively is a problem encountered by conservation managers and researchers worldwide (e.g. Sherley 2001; Venette et al. 2002; Thompson 2004; Hedgren & Weslien 2008; Evangelista et al. 2009; Singh et al. 2009; de Tores & Elscot 2010). Due to the relatively small size and fragility of most invertebrates, successful monitoring has necessitated designing techniques that avoid laborious hand searching or the destruction of natural refuges (e.g. Sherley 2001; Bowie et al. 2006; Hodge et al. 2007). As a result, artificial refuges are often utilised in species conservation for a variety of taxonomic groups (commonly birds, lizards and invertebrates) and can be used to monitor important parameters such as population size, density, demographics, and to provide organisms for critical field and laboratory studies (Webb & Shine 2000; Bowie & Frampton 2004; Hirai 2006; Lettink & Patrick 2006; Lettink & Cree 2007; Bell 2009; Bowie 2010a; Croak et al. 2010; Fernández-Olalla et al. 2010; Grillet et al. 2010; Allen et al. 2011; Lettink et al. 2011).

Weta (Anostostomatidae) are large flightless Orthoptera endemic to New Zealand. Anostostomatidae in New Zealand are represented by four groups: tree weta (genus *Hemideina*), giant weta (genus *Deinacrida*), ground weta (genus *Hemiandrus*) and the tusked weta (genera *Anisoura* and *Motuweta*). All seven species of tree weta (*Hemideina* spp.) are nocturnal (Morgan-Richards et al. 2001). Four species (*H. thoracica, H. trewicki, H. crassidens* and *H. femorata*) are common and have adapted well to New Zealand's modified landscape (Gibbs 2001). By comparison, *H. ricta* is classified as 'range restricted' (Hitchmough et al. 2005), being only known from the eastern end of Banks Peninsula, Canterbury (Brown & Townsend 1994).

All *Hemideina* species occupy galleries in trees and logs (Jamieson et al. 2000; Field & Sandlant 2001); however *H. ricta*, *H. maori* and *H. femorata* are also found in rock crevices (Townsend et al. 1997; Jamieson et al. 2000; Scott et al. 2012) or in dead, hollow *Aciphylla* flower stalks (Bowie, unpubl. data). Tree weta are opportunistic, occupying existing tunnels created predominantly by the larvae of the kānuka longhorn beetle (*Ochrocydus huttoni*), or using cracks and crevices in dead wood (Field & Sandlant 2001). Tree weta do not excavate their own galleries, but may modify the tunnel or entrance hole to enable them to fit snugly through (Field & Sandlant 2001). They are often gregarious, although the degree varies according to species. Field & Sandlant (2001) found over 51% of *H. femorata* in groups of one male and one or more females, while this only occurred in around 21% of *H. crassidens.* Many unoccupied potential galleries were found, suggesting that gallery numbers were not a limiting factor on population size (Field & Sandlant 2001).

Tracking tunnels are a recent method used to monitor the presence of tree weta and giant weta (Watts et al. 2008, 2011), although this method does not distinguish between one or more individuals and is dependent on mild weather. Hand searching has been used by Townsend et al. (1997) for *H. ricta* and *H. femorata* on Banks Peninsula but is time-consuming and required some weta to be extracted from holes and by rotten log destruction, while others were seen but could not be extracted for accurate species identification. The use of artificial refuges (here called 'weta motels') avoids many of the issues above and can be used to aid monitoring and translocation for restoration and conservation purposes (Bowie et al. 2006; Bowie 2010b). Weta motels of many designs have been used successfully by entomologists for research and conservation purposes for approximately two decades. The first published weta refuge was a simple box design used to study stridulatory behaviour in the Wellington tree weta (*H. crassidens* (Ordish 1992)). Trewick & Morgan-Richards (2000) published a design of a multi-compartment 'condominium-style' refuge for monitoring tree weta species *H. trewicki* and *H. thoracica*. More recently, refuges designed for non-destructively monitoring weta (Green 2005; Bowie et al. 2006) and spiders (Hodge et al. 2007) have been smaller, single-entrance types.

Bowie et al. (2006) described a single-entrance (18 × 18 mm), single-cavity motel design that had an acetate-sheet viewing window placed against the tree to shut out the light for the occupants. They used 50 weta motels at each of six sites in Canterbury, New Zealand, and found that weta uptake rate was extremely low, with only 27 out of 300 (9%) motels housing weta over a 12-month period. Instead, spiders were the main inhabitants of this type of motel (Hodge et al. 2007). This indicated a need to improve the design to increase the occupation rates of tree weta. Issues with the Bowie et al. (2006) design were threefold. First, there was the need to remove the motel from the tree to view occupants of motel; second, the acetate sheet was prone to trapping condensation, making it hard to observe inside; and third, the entrance hole was too big, making weta vulnerable to predation (Bleakley et al. 2006). Other considerations not addressed in their study were the use of possible lures and an assessment of the optimal placement of motels in the field to increase weta occupation rates. Trewick & Morgan-Richards (2000) found that the location of the 'roosts' appeared to influence the number of invertebrates that used them. They suggested 'single or few-hole roosts…' be placed on '…trees at high density and with site replication' for weta monitoring, and that roosts need to be in place for several years before management practices are due to be implemented. Moreover, Bleakley et al. (2006) completed the most comprehensive investigation on the design and use of artificial refuges for the Wellington (*H. crassidens*) and Auckland tree weta (*H. thoracica*) in the laboratory and the field. They found that the two species had different refuge preferences and surmised that other tree weta species were also likely to differ in their preferences.

The aims of this research were to (1) describe a modified artificial refuge design, (2) examine the influence of canopy and subcanopy cover on weta motel occupancy rates, (3) test whether using lures increases numbers of tree weta observed in modified refuges, and (4) reassess the distribution of tree weta identified by Townsend et al. (1997) on eastern Banks Peninsula.

Methods

Artificial refuge design

Motels were constructed from untreated kiln-dried wood (*Pinus radiata* or *Pseudotsuga menziesii*) and cut with a sloping roof and parallel base containing the entrance hole. Two sizes of weta motel were used: 50 × 50 × 210 mm for canopy cover and subcanopy density assessment (with an internal cavity of c. 64 cm³); and a larger 90 × 45 × 250 mm for the lure trial (internal cavity c. 160 cm³). Both sizes of motel were based on the 'pencil box' design (Fig. 1) and had an entrance hole 14 mm in diameter to prevent mice (the smallest mammalian pests) from entering and eating the weta (Bleakley et al. 2006). The motels have a swivelling observation panel on the front with a sloping and tapered edge to allow it to be closed tightly to keep the internal cavity dark. The cavity was routered to

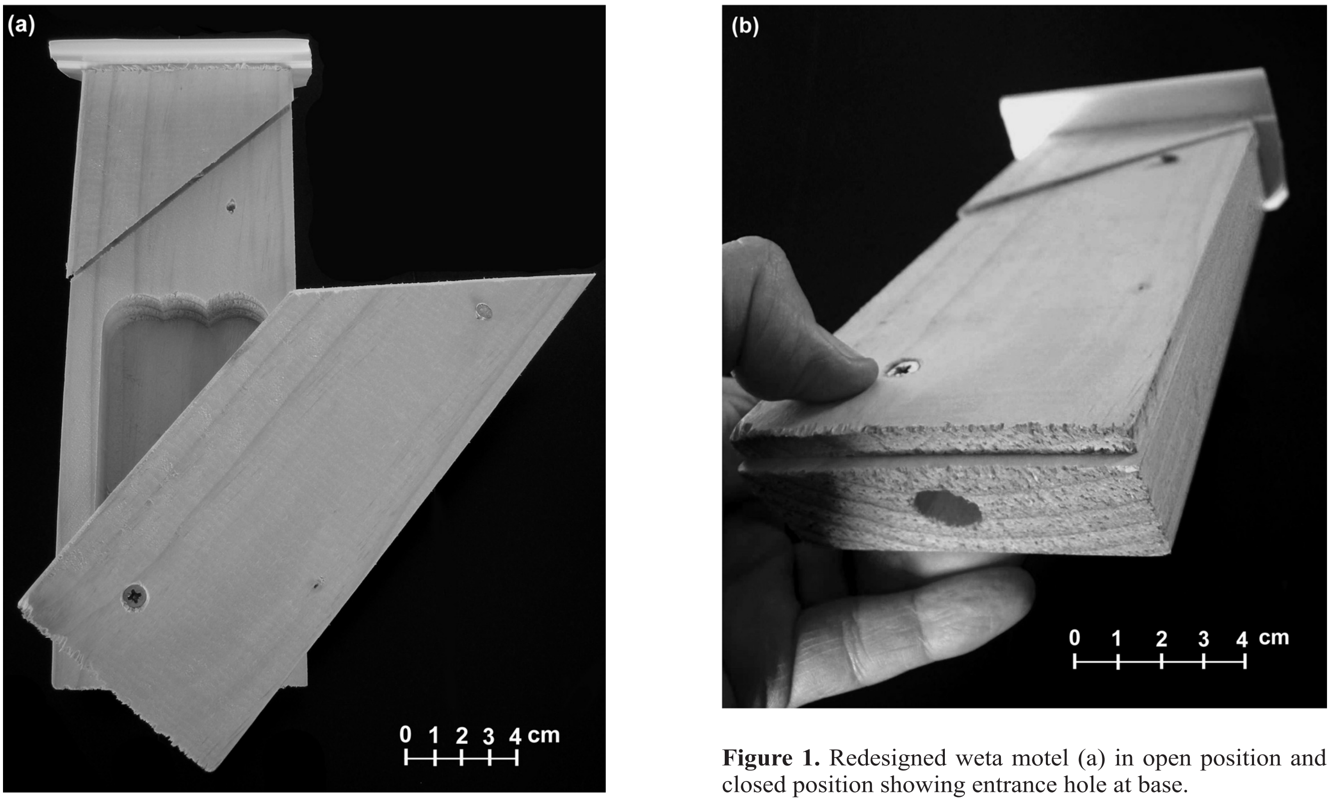

Figure 1. Redesigned weta motel (a) in open position and (b) closed position showing entrance hole at base.

allow room for several adult tree weta. Portions of plastic ice cream containers were attached by staple gun to act as a roof to prevent motels becoming waterlogged and rotten. The maximum possible occupancy of these two types of motels was compared, using the greatest number of individuals recorded in each motel design across all studies.

Influence of canopy cover and subcanopy density on occupancy rate

Between 17 and 22 December 2003 a total of 150 motels were placed at 10 sites (i.e. 15 per site) on the eastern part of Banks Peninsula. Vegetation was remnant native forest dominated by fuchsia (*Fuchsia excorticata*), kānuka (*Kunzea ericoides*), lacebark (*Hoheria angustifolia*), mountain holly (*Olearia ilicifolia*), ribbonwood (*Plagianthus regius*), māhoe (*Melicytus ramiflorus*), kaikōmako (*Pennantia corymbosa*), broadleaf (*Griselinia littoralis*), and kōwhai (*Sophora microphylla*). Motel locations ($n = 150$) were evaluated for degree of canopy cover by visually assigning as open (0–50%) or dense (>50%) for vegetation above 2 m in height. Sites were also evaluated for the degree of subcanopy vegetation density by assigning sites as open (0–50%) or dense (>50%) for vegetation 2 m or lower. Motels were checked once between 11 February and 17 March 2004 for the number of motels inhabited by tree weta. Comparisons in the proportions of motels with weta under dense or open canopy conditions were made using a Fisher's exact test. Separate tests were run for motels located either in the canopy or subcanopy vegetation.

Influence of potential lures on occupancy rate

The effect of various lures on occupancy rates was investigated over summer of 2007/08. On 12 December, 40 new (unused) weta motels were placed along the fence line of a native reserve in eastern Banks Peninsula known to contain *H. ricta*. Vegetation mostly consisted of large kānuka and ngaio (*Myoporum laetum*), with a thick undergrowth of ferns, bracken (*Pteridium esculentum*), gorse (*Ulex europaeus*), various grasses, and native seedlings.

The larger motels (described above) used in this experiment were sufficient to accommodate at least four adult weta and replicated the natural harems that weta themselves form, where females are guarded by a single adult male (Field 1993; Kelly 2006). Motels had one of four treatments added: male tree weta frass, female tree weta frass, peanut butter (known to be attractive to some weta) and a control containing no lure. To apply the lure, a single fresh *H. ricta* frass pellet or comparable amount of peanut butter was squashed onto the inside of the motel, beside the entrance hole. The motels were placed in blocks of four, with one of each lure treatment present. Ten replicates were used. The motels were attached with wire to the shady side of native trees or fence posts, approximately 1 m above the ground, with motels in the same block placed 5–10 m from one another. The distance between each block was approximately 40 m. The placement of each lure treatment within a block was randomly chosen. The motels were checked on 21 December 2007, 27 December 2007, 4 January 2008, 25 January 2008, 30 June 2008, and 6 December 2008, that is, days 9, 15, 23, 44, 182, and 350 after placement. The frass and peanut butter were replaced each time the motels were checked.

The effect of the lure treatment on changes in motel occupation was analysed using a generalised linear model with a logit link function. Significance of the lure treatment was assessed using a Wald test, and a post hoc pairwise comparison of the mean occupancy rates was conducted using Fisher's least significant difference (LSD) test ($\alpha = 0.05$). All statistical analysis was conducted using GenStat version 15 (VSN International).

Reassessment of tree weta distributions on Banks Peninsula

The eastern half of Banks Peninsula was surveyed for both species of tree weta using motels, to compare with the findings of Townsend et al. (1997). Ten motels (of mixed size) were put out at each of 65 locations where tree weta habitat was present and landowner permission could be gained. Motels were tied to tree species known to harbour tree weta including fuchsia, kānuka, lacebark, mountain holly, ribbonwood, māhoe, kaikōmako, broadleaf, kōwhai, tōtara (*Podocarpus totara*), and pigeonwood (*Hedycarya arborea*). Motel occupancy by the two tree weta species was assessed annually where possible over a period of 4 years. Assessments were carried out usually between November and February, where the number, sex, and species were recorded. Tree weta found were identified to species, and possible hybrids were verified by counting the number of stridulatory ridges as in Townsend et al. (1997). A Welch's *t*-test was used to test for differences in mean altitude of sites occupied by each species. Site locations from previous studies (Brown & Townsend 1994; Morgan-Richards & Townsend 1995; Townsend et al. 1997) were recorded in NZMS 260 map reference units, which were converted via the Land Information New Zealand website to match the coordinate system used in the current study.

Results

Influence of canopy cover and subcanopy density on occupancy rate

Of the 150 motels, 139 were found still attached to trees, but only 20 were occupied by *H. ricta*. Of these a significantly higher portion of motels were occupied by *H. ricta* found under open canopy cover (63.6%) than in dense canopy (5.1%) ($\chi^2 = 51.46$, d.f. = 1, $P < 0.001$, $n = 139$, Fig. 2).

The difference in weta occupation between the two subcanopy density categories (open 0–50% and dense >50%) was highly significant, with motels in open subcanopy density sites having higher occupancy (29.2%) than those in dense subcanopy sites (1.4%) ($\chi^2 = 21.84$, d.f. = 1, $P < 0.001$, $n = 139$, Fig. 2). Overall, 64% of motels under open canopy cover and

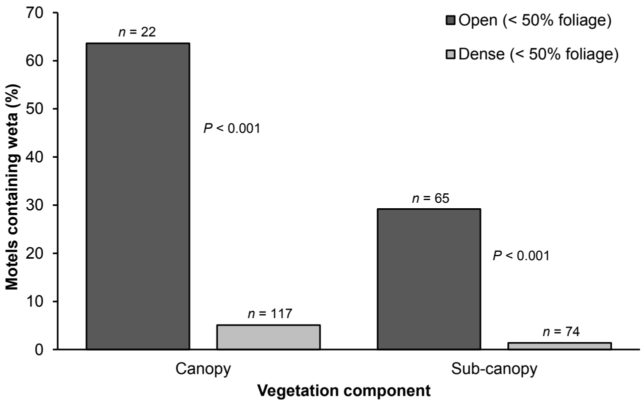

Figure 2. Effect of vegetation structure on weta motel occupation by tree weta, *Hemideina ricta*.

open subcanopy density contained *H. ricta*. By comparison, only 11% of motels were occupied under dense canopy cover/open subcanopy density and just 1% under dense canopy cover/dense subcanopy density. No sites had the open canopy cover/dense subcanopy density combination.

Influence of potential lures on occupancy rate

Banks Peninsula tree weta were found in motels as early as 9 days after placement. There were significant differences in occupation rates between the different lure treatments (χ^2 = 9.557; d.f. = 3; P < 0.001; n = 40). Post hoc LSD tests indicated that motels lured with female frass showed significantly higher occupation than the control, male frass and peanut butter options (Fig. 3), with occupation increasing to a maximum of 80% after 182 days. At this sampling time, the weta from all treatments had a sex ratio approaching a 2:1 female bias (16♀:9♂). Of these weta, 11 were adults, 6 were subadults and 8 were immature. After 350 days, 6 of the 10 motels containing peanut butter showed brushtail possum (*Trichosurus vulpecula*) scratch marks, while only one other motel (male frass treatment) had scratch marks from all the other treatments. Chi-square analysis showed peanut butter had a higher than expected possum interference (χ^2 = 17.14, d.f. = 3, P < 0.001, n = 40).

Reassessment of tree weta distributions on Banks Peninsula

The distributions of *H. ricta* and *H. femorata* on eastern Banks Peninsula from weta motel sampling were very similar to those found by Townsend et al. (1997) using hand-searching (Fig. 4a and b). The western distributional limit of *H. ricta* was very similar between the two monitoring methods, with all individuals found east of Pigeon Bay and Akaroa Harbour. *Hemideina ricta* were found at sites between 60 and 690 m above sea level, whereas *H. femorata* had a slightly wider range, between 30 and 764 m. The two highest altitudes for *H. femorata* were 764 m and 735 m at Mt Sinclair and Mt Fitzgerald respectively. However, *H. femorata* generally occupied motels at lower-altitude sites than *H. ricta* with mean altitudes of 289 m and 420 m respectively (t_{29} = −2.23, P = 0.034). The two weta species were not found cohabitating in any motels even though they were found in weta motels within 200 m of each other at three separate sites. No weta with intermediate numbers of stridulatory ridges (which is known to indicate that hybridisation has occurred; Townsend et al. 1997) were found.

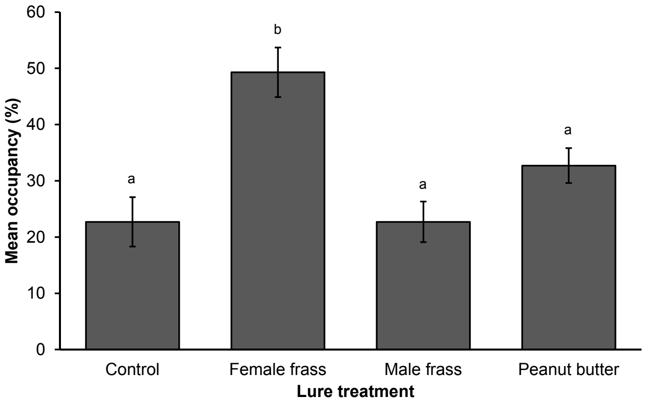

Figure 3. Effect of lure treatments on weta motel occupation by tree weta, *Hemideina ricta*. Standard error bars with different letters above indicate they are significantly different (P < 0.05).

The maximum number of weta found in the larger (160 cm^3) weta motels was seven (one male and six females on 10 February 2011), whereas the smaller motels (64 cm^3) contained a maximum of four weta (one male and three females on 4 February 2010). Cave weta (Rhaphidophoridae), leaf-vein slugs (Athoracophoridae) and *Artystona* spp. (Tenebrionidae) were also commonly found inhabiting the motels, with *Artystona* often cohabitating with tree weta.

Discussion

The weta motels used in this study were found to be useful for monitoring the Canterbury tree weta *H. femorata* and the range-restricted Banks Peninsula tree weta *H. ricta.* Cave weta and other native invertebrates also use this motel and it is very likely that it would be successful for monitoring weta from other parts of New Zealand and even other invertebrate species that use a similar type of cavity worldwide. This method of monitoring New Zealand's rarest tree weta species should

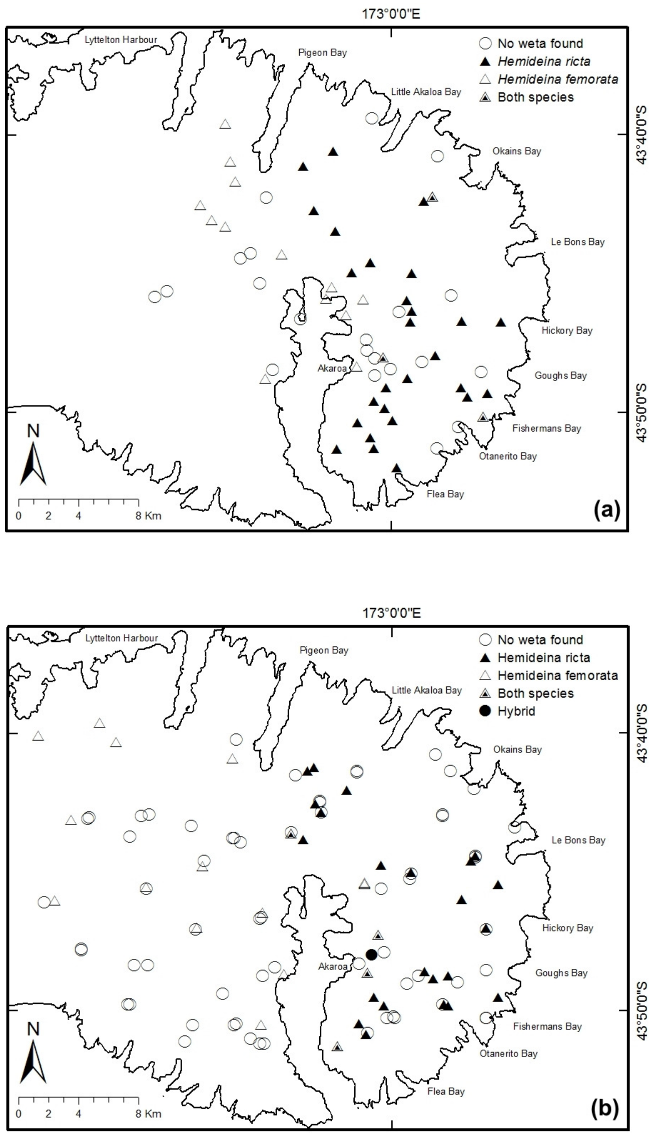

Figure 4. Distribution of tree weta, *Hemideina ricta*, on eastern Banks Peninsula based on (a) use of weta motels and (b) hand searching for weta (described by Townsend et al. 1997).

be useful in long-term assessment of population health and further demonstrates the usefulness of artificial refuges in the conservation field.

Artificial refuge design

The main differences between this weta motel design and that of Bowie et al. (2006) were the absence of an acetate sheet used as a 'window', and the narrower entrance hole (14-mm diameter). In that 2006 study, the acetate sheet tended to trap more moisture in the cavity than in all-wood motels. Given the hygroscopic nature of wood, the new all-wood design used here seemed to assist in reducing moisture levels. As tree weta appear to avoid the upper and lower extremes of humidity, and wooden refuges buffer against humidity changes (Field & Sandlant 2001), the motels without acetate are more 'natural' and therefore more attractive to weta. This is supported by Bleakley et al. (2006) who recommend that designs not include clear material such as acrylic plastic. A smaller entrance size was used in the current study as it had been shown by Bleakley et al. (2006) to prevent mice from entering. However, the fact that the sex ratio biased towards female (16♀:9♂ at 6 months) in our lure experiment could also mean that the smaller entry size in our motels restricted sexually dimorphic adult males, whose head capsule size is larger than that of the female (Field & Sandlant 2001).

The larger sized motel without added frass has recently contained as many as seven adult tree weta at once and the motels from all treatments combined had a maximum occupancy rate of 80% after 6 months. Overall, the uptake rate of motels after just 9 days in the lure experiment was much quicker than reported in previous studies (Ordish 1992; Trewick & Morgan-Richards 2000; Spurr & Berben 2004), where tree weta took 2–3 months to begin colonising. In this case, the population of *H. ricta* may be high compared with the number of available refuges (i.e. demand is greater than the supply). As might be expected in a regenerating forest, a paucity of natural galleries in relation to the size of the weta population may force the weta to look elsewhere for a refuge, increasing the uptake rate of the weta motels. Unfortunately, no reliable technique has been found to estimate weta abundance accurately and consistently to validate this. Furthermore, factors such as the successional status of the forest, the density of natural weta galleries, population structure, and metapopulation dynamics should all be taken into account before considering any estimates of population size.

As the motels used in this study were made from kiln-dried wood, it is expected that they will last as long as the earlier prototypes described in Bowie et al. (2006), which were made with the same material; many are still intact after a decade of use. Although motel deterioration through rotting is likely in wetter climates, the main requirement over time is to loosen the tie wire around the tree as it grows to prevent the wire cutting into the cambium.

Influence of canopy cover and subcanopy density on occupancy rate

Our research provides some valuable insight in that site characteristics such as canopy cover or subcanopy density appear to be important factors for colonisation of motels by *H. ricta* and should be considered when sampling this species. Motels were more frequently occupied by weta where canopy and subcanopy vegetation was sparse. This may be due to a number of reasons. First, weta may be less abundant in dense forest. Second, there may be more natural refuges in dense forest and therefore less demand by weta for motels. Third, motels may be more easily found by weta in less dense vegetation. Fourth, kānuka longhorn tunnels, often used by weta, may tend to be in more open areas and provide a reservoir population that colonise motels. Finally, these open areas may provide any number of unmeasured favourable environmental conditions, such as more sunlight and precipitation, when compared with areas of dense canopy and subcanopy cover.

Influence of potential lures on occupancy rate

A maximum of 80% occupation of motels with a female frass lure is markedly greater than recorded previously. Faecal pellet odours are probably an important cue for males to locate refuges with females and perhaps for females to find suitable refuges (as indicated by presence of other females) that can be used to increase occupancy for monitoring (Barrett 1991; Field & Sandlant 2001; Guignion 2005). Weta are thought to be able to differentiate between female and male frass (Field & Jarman 2001), and this appeared to be supported by the results; however, natural weta galleries containing more than two weta have a female bias due to their social harem system. In terms of monitoring weta, the use of frass could be considered time-consuming and may bias comparisons of uptake rates when comparing with studies that did not use frass. Therefore, this technique should be considered for use only when a fast uptake rate of motels is required for research purposes, as may be the case for rare species.

Peanut butter may be an unsuitable lure for weta not only because it was unattractive, but also because possums and rodents are known to be attracted to the scent. Given that possums and rodents are known predators of tree weta (Rufaut & Gibbs 2003) and that 60% of the motels treated with peanut butter were scratched by possums, use of weta motels lured with peanut butter is not recommended apart from on predator-free islands or sanctuaries.

A large percentage of juveniles (24%) and subadults (32%) was found in the motels in the lure experiment. This may be because natural galleries have already been occupied by adults who are unlikely to actively search for new galleries. Ordish (1992) found 6th and 7th instar Wellington tree weta (*H. crassidens*) were often the first to colonise weta motels, and a previous study has shown juveniles and subadults to be much more transient than adults (Kelly 2006).

Reassessment of tree weta distributions on Banks Peninsula

The monitoring of the weta distributions showed that this motel was suitable for both tree weta species and that the range-restricted *H. ricta* does not appear to be shrinking in its distribution, which bodes well for the conservation of this species. Forest fragmentation probably has less effect on *H. ricta* than *H. femorata*, given the latter is more reliant on a tree habitat. Active restoration and natural regeneration should create corridors and aid movement through the landscape. No morphological evidence of hydrids was found in this study, unlike Morgan-Richards & Townsend (1995), which found evidence that hybridisation had occurred between the two tree weta species. Collecting DNA from weta in motels would be a more precise approach to determine to what degree hybridisation occurs, and the relatedness of these isolated populations. Several *H. femorata* were found in motels 250 m higher than the maximum altitude of 450 m previously reported for this species (Townsend et al. 1997). Interestingly, these weta were found just beyond the western limit of *H. ricta*, possibly indicating that this species may exclude *H. femorata* at upper altitudes. Such parapatric distributions are commonly seen with other tree weta species in New Zealand, where little coexistence is seen between the distributions of *H. femorata* and *H. crassidens* in the northern South Island, and *H. crassidens* and *H. thoracica* in the North Island, despite populations virtually overlapping one another (Trewick & Morgan-Richards 1995).

Conclusions

The weta motel described here was found to be considerably better for monitoring tree weta than earlier designs and achieved high occupancy rates for *H. ricta*. For effective monitoring of this species we recommend placing motels on edges of reserves or where there is little canopy cover, and where subcanopy density is sparse. Lure studies showed that female frass placed inside weta motels significantly increased *H. ricta* occupation up to 80% after 6 months. The use of frass as a lure could also be tested for other weta species or other gregarious motel inhabitants such as darkling beetles (*Artystona* spp.) or leaf-vein slugs. But as lures add another variable to monitoring, their use should generally be considered only for rarer species, where obtaining sufficient samples may be an issue. Our sampling indicates that populations of *H. ricta* on Banks Peninsula appear to be stable, but long-term monitoring of weta motels at many sites will eventually provide a clearer picture of their conservation status.

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